International Journal of Reconfigurable and Embedded Systems (IJRES)
Vol. 13, No. 2, July 2024, pp. 472~482
ISSN: 2089-4864, DOI: 10.11591/ijres.v13.i2.pp472-482

Frequency reconfigurable microstrip patch antenna for multiband applications

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Article Info

Article history:

Received Jun 30, 2023
Revised Oct 25, 2023
Accepted Dec 9, 2023

Keywords:

Frequency reconfigurable antenna
Microstrip patch antenna
Return loss
RF-MEMS
Voltage standing wave ratio
Wireless communication

ABSTRACT

Wireless communication technology is well-established, and several antennas have been developed and produced specifically for this purpose. However, antenna performance and communication system development need to be enhanced in order to adapt to the present era. The performance of the antenna is significantly influenced by its design. Thus, this work produced a novel wideband antenna design via the use of a frequency reconfigurable approach. In the recommended study, microstrip patch antennas (MPAs) were used in wideband applications to switch frequencies using shunt-series microelectromechanical systems (MEMS). The suggested antenna, which has two switches built into it, is tested in ON-ON, OFF-ON, and OFF-OFF switching scenarios. Radiation pattern, voltage standing wave ratio (VSWR), gain, bandwidth, and return loss are among the antenna performance metrics used to assess the suggested antenna's performance in each switching situation. The simulation findings suggest that the optimal antenna design for usage in wireless communication systems is one that works well with a shunt-series MEMS switch.

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1. INTRODUCTION

The reconfigurable antenna (RA) is a more appealing design choice than the fixed antenna because it may provide variable radiating properties like resonance for wireless communications systems. With this extra degree of control, it might be possible to adjust in the field to comply with a given standard, compensate for manufacturing defects, and future-proof a system against changing standards. Sensitive wireless configuration device tuning often involves the use of a varactor diode or a tuned resistance. RAs have garnered a lot of attention recently due to their potential use in communications, electronic surveillance, and countermeasures. In RAs, switching permits the shape of the radiating element to be altered. Antennas that support many wireless protocols will be necessary for cognitive communication systems in the future [1]–[5].

Because multiband antennas may cover several frequencies with a single antenna, they are particularly useful in modern wireless applications. However, in order to increase the effectiveness of their rejection of out-of-band interference, fixed multiband antennas sometimes need sophisticated filters with

stringent criteria. Since the filter is often quite large, any communication system might become more intricate. RAs, which improve out-of-band noise rejection, may help overcome these restrictions. Antennas that can change their frequency, pattern, polarisation, and other properties in response to outside stimuli are known as RAs. Depending on the application, reconfiguring might include more than one distinct feature. It is feasible to classify RAs into three categories. Reconfigurable frequency is the starting point for the first group. The objective is to optimise the antenna's working frequency and create a tiny terminal with a single multipurpose antenna for many applications [6]–[10].

Recently, there has been a lot of interest on frequency reconfiguration due to the introduction of revolutionary concepts in wireless communication, such as cognitive radio, which uses wideband sensing and programmable narrowband transmission. The second classification alters the radiation pattern while keeping the same frequency range in order to meet system requirements based on pattern reconfigurability. The third category is based on the ability to change polarisation from linear to circular and from left-hand (LHCP) to right-hand (RHCP) circular. Reconfigurability may be achieved by a variety of switching technologies, including optical switches, field-effect transistors (FETs), PIN diodes, and radio frequency-microelectromechanical systems (RF-MEMS) switches. Many research endeavours have focused on RF-MEMS antenna devices presentation. However, complete demonstration of RF-MEMS integration with the antenna has not been accomplished. An innovative frequency-RA design is presented in this paper. Devices for RF-MEMS switching is used. An electrical reconfiguration of the aperture may be accomplished by changing the statuses of the switches. We chose microelectromechanical systems (MEMS) switches over FET switches and traditional PIN diodes as switching components because of their superior RF properties, which include linearity, insertion loss, isolation, and power consumption up to around 40 GHz [11]–[15].

The suggested antenna covers the necessary frequency bands for universal mobile telecommunications system (UMTS), personal communication system-digital communication system (PCS-DCS), wireless local area network (WLAN), and worldwide interoperability for microwave access (Wi-MAX) applications. For WLAN and Wi-MAX applications, this antenna has the ability to resonate in three frequencies concurrently. RAs are very advantageous for modern communication systems since they may provide a variety of characteristics in terms of operating frequency, polarisation, and emission pattern. The emission pattern of an antenna may be utilised to locate target signals and avoid interference or electrical noise. These antennas are often used to strengthen communications security. The aforementioned factors have led to a notable need for radars, satellite communications, wireless communications, and related industries [16]–[22]. Phase-shifted antenna arrays are often equipped with pattern reconfiguration; nevertheless, due to their size, weight, and installation complexity, they may not be suitable for many applications. Recently, a growing range of reconfiguration antenna designs have been put forward, most of which utilise on switching mechanisms to alter current pathways, regulate current distribution, and give behaviour that can be changed based on patterns. Microstrip patch antennas (MPAs) play a significant role in the area of RAs because to its features, which include tiny size, light weight, low profile, and compatibility with microwave monolithic integrated circuit (MMIC) design. Due to its superior isolation and low insert loss, RF-MEMS switches are a widely used choice in wireless communication systems. This work proposes a revolutionary reconfigurable micro strip antenna. The Ansoft high frequency structure simulator (HFSS) software duplicates the states of the antenna by using metal strips and air gaps in place of "off and on" switches to control RF-MEMS switches. The authors want to use an inexpensive FR4 epoxy substrate to construct a prototype antenna for work related to this research [23]–[26].

2. PROPOSED METHOD

RAs have a wide range of creative and adaptable uses. The reconfigurable feature has several benefits in wireless applications, including mobile terminals of the fourth and fifth generations (4G and 5G). A RA needs sufficient active components to be able to change its characteristics. The networks that regulate the circuitry grow more costly and complex in terms of biassing as a result of these premium active components. The radiating patch's current distribution, which can be altered by changing the patch's current flow, determines an antenna's properties. A varactor diode, PIN diodes, or MEMS switches are examples of the active element (or switches) needed to alter the current distribution in the radiating patch. Accordingly, the other authors have suggested and we have assessed RAs for enhanced wireless terminals. If the front-end circuitry's characteristics, including frequency, pattern, and polarisation, are programmable, a wireless system may become more simple, smaller, and less expensive. RAs have been used more often in recent years to maximise RF system performance. Future cutting-edge wireless communication and mobility systems may benefit from these sorts of antennas. Other methods to meet the requirements might include the usage of active components like switches or capacitors.

However, the number of re-configurable parameters that are accessible is determined by the use of active components. Antenna properties may be altered via varactor diodes, PIN diodes, optically actuated

switches, and RF-MEMS switches. A fast-switching rate is particularly useful to quickly change the functioning of the antennas. The majority of RF-MEMS switch applications usually function in the region of 1-200 ns. An antenna using an integrated varactor diode may sacrifice a large tuning range in exchange for very high nonlinearity. However, PIN diodes may be used in RA system designs due to their short switching periods (100–200 ns), which allow for quick dynamic reconfiguration. This review research has investigated several types of RA s for wireless systems with single and multiple reconfiguration features. The frequency reconfigurable antenna (FRA) design requires careful consideration of fundamental aspects because to the physical constraints of contemporary wireless devices like as smartphones and tablets, as well as their ability to switch between frequency bands dynamically or continuously within a certain frequency range. Certain methods are effective in changing the configuration of an antenna system.

Using PIN diodes is the most often used technique for altering the electrical length of an antenna radiator. The working band may be changed by the varactor diode, enabling the switching from wideband to narrowband or vice versa. The resonance frequency may be determined using the matching network. Four more approaches are as follows: either altering the input-impedance or planning the antenna arrangement to include a shorting post. This is why changing an antenna's working spectrum to the appropriate frequency range may be done in a variety of ways. To alter the antenna's working band, a varactor is placed into the meander-line slot. The suggested construction is based on a composite right/left-handed gearbox line, as shown in figure composite right/left handed-transmission line (CRLH-TL). A series capacitance and a shunt capacitance are the two capacitances/inductances included in the CRLH-TL. Because of its remarkable frequency-reconfigurable capabilities, the operating frequency range of 4.13 to 4.50 GHz at 0-36 V may be appropriate for 5G base applications.

This field includes the frequency and pattern of radiation. It is possible to improve system performance, lower noise levels, and save energy by altering an antenna's radiation pattern for omnidirectional, end-fire, and broadside modes. Less interference occurs between different wireless providers. There are several benefits to lowering the quantity of antennas needed for frequency tuning. Frequencies are switched by active components like PIN diodes and varactors. The current distribution throughout an antenna's radiating patch is a critical component in pattern reconfiguration. By adjusting the antenna's current distribution via the use of the slot or slit structure, the radiation pattern is directed more successfully. The antenna may function in three distinct frequency bands thanks to the radiator patch of the suggested design, which is made up of four similar parts. Twelve parasitic elements are symmetrically matched with six radiators in the circular aperture to define radiation pattern and frequency. For WLAN, broadband, Zigbee, and satellite-digital multimedia broadcasting (S-DMB) services, diode switching states allow 450-step radiation pattern steering. To enable the change of the operating bandwidth from narrowband to wideband or vice versa, a corresponding network or reconfigurable filter is included into the structure's feed line. It has been utilised to modify the ground plane specifically for patch or monopole antennas. In order to regulate the current flow of the radiation patch, a 2 PIN diode is positioned in the centre of the slot. For many wireless applications, it is very desirable to be able to achieve an impedance bandwidth spanning from 22% to 78%. Additionally, wideband services and other wireless systems like 4G, WLAN, WiMAX, and satellite phones are kept apart by using the Narrowband/Wideband reconfiguration capabilities. This improves the adaptability of the antenna system and qualifies it for multi-mode wireless communications.

Applications like as imaging, sensing, tracking, and radar benefit greatly from the combination of reconfigurable frequency and polarisation. The most efficient use of the available spectrum requires frequency reconfiguration, even while polarisation diversity helps to reduce multipath fading effects and increase channel capacity. Many other designs have been suggested because of how intriguing this combo is. To allow re-configurability in an antenna system, switches placed on top of the antenna resonator are made possible by the electromagnetic band gap (EBG) or meta-surface structure technology. Still, the most popular approach is to combine active components like PIN diodes and varactor diodes to provide frequency and polarisation reconfigurability. 2.4 and 3.4 GHz are possible frequency adjustments for 4G/5G multi-mode communication systems with varying polarisation. This study provides a thorough examination of FRAs with both single- and multiple-reconfiguration capabilities. To enhance the design parameters and provide size reduction strategies in a categorised way, additional methodologies were used. Reduced attention was paid to low frequency designs as high frequency designs were the suggested study option. The low FRA design, including geometrical aspects, appropriate for wireless applications, has been carefully investigated in this study in light of the aforementioned material. Along with pattern reconfiguration, polarisation characteristics, and simultaneous and flexible reconfiguration, this article also offers design guidelines and processes.

MEMS devices combine sensors, actuators, electronics, and mechanical components onto a single silicon substrate via the use of microfabrication techniques. In micro-fabrication, batch micromachining based on lithography is a popular process with several benefits, one of them being cost-effectiveness in large-scale production. Quartz and high-resistance gallium arsenide (GaAs) wafers are also used as MEMS

substrates in semiconductor microfabrication procedures. MEMS switches may have the mechanical form of a thin metal cantilever, an air bridge, or a diaphragm. They may be electrically linked to an RF transmission line either in series or parallel. Depending on how the MEMS switch is operated, polar ceramics like barium-strontium titanate (Ba,Sr)TiO_3 (BSTO) may have a capacitive (metal-insulator-metal) or resistive (metal-to-metal) contact state. Every kind of switch offers a different set of benefits, whether it is in terms of manufacturability or performance. Changeable ferroelectrics have a lot of promising applications in tunable microwave devices. The spring constant, k, of RF-MEMS switches governs their primary mechanical functions in everything that was used. Since the deflection of the beam relies on the spring constant k and we want a bigger deflection with a given force, we always desire less k, or less stiff material, for a given RF-MEMS switch. In this study, we used a meander form of the Serpentine flexure type to reduce the k value.

Microstrip antennas are well recognised for their cost, low weight, rigidity, low profile, and ability to accommodate both planar and non-planar surfaces. They also have a reputation for being simple to install. They are primarily used in mobile communications devices because to their adaptable designs and affordable prices. Reconfigurable aperture (RECAP) and microstrip antenna topologies have been prioritised in order to get multiple octave tunability. The development of RF-MEMS switches has led to an upsurge in research on reconfigurable multiband slot antennas. Neural networks (NNs) and evolutionary algorithms have been used in reconfigurable multiband antenna designs much more often in the last several years. Fractal antennas have a self-similarity property that may be built upon to create multiple-frequency antennas. One benefit of these antennas is that their patterns radiate similarly over a wide range of frequencies. The Sierpinski gasket, which has been extensively investigated, is the main predecessor. Several self-similar fractal patterns have impacted multi-band or small antenna designs. Diverse fractal geometries, including Koch Island, Sierpinski gasket, Sierpinski carpet, Hilbert curve, and Minkwoski, have been used in fractal antenna projects. This work has built and simulated multiple-frequency fractal antenna meander-based RF-MEMS switches. Altering the sequence of iterations or electronically adjusting the antenna to a certain frequency is further options. The number of losses is decreased by using MEMS switches. This is necessary in order to provide high reconfigurability and prevent mismatched systems from developing from switch connections or disconnections. Furthermore, the design of the system is limited by the integration of the switches with the antenna. The same materials must be used for the construction of the antenna and the switch structure. The size limitation of the antenna system is minimal, and the maximum power that it can transmit is great, since the switches' dimensions are often set. Additional devices that might use this technology include military-grade antenna designs, tunable filters, and signal splitters.

In addition, a fractal-shaped microstrip antenna is proposed in this study, together with information on its return loss, voltage standing wave ratio (VSWR), and radiation pattern. The results demonstrate that it has the qualities required to function for a variety of wireless communication applications. It provides return losses of less than -10 dB at several frequencies, enabling multiband applications. Switches are replaced with short, open channels as a proof of concept. Additionally, omnidirectional radiation with a VSWR of less than two is present. It is so tiny since it is a microstrip antenna. Therefore, the suggested antenna satisfies the requirements for being modest in size and supporting several bands.

$$Pl = Pl_{eff} - 2\Delta Pl \tag{1}$$

$$Pw = \frac{c}{2f_{res}\sqrt{\frac{(\varepsilon_{res}+1)}{2}}} \tag{2}$$

In this case, Pl stands for the patch's length, Pw for its width, ΔPl for its length extension, Pl_{eff} for its effective length, f_{res} for the resonance frequency, ε_{res} for the dielectric constant value, and c for the light's speed, which is 3×10^8. Here, (3) and (4) are used to determine the effective length Pl_{eff} and the extension of length ΔPl, respectively.

$$Pl_{eff} = \frac{c}{2f_{res}\sqrt{\varepsilon_{reseff}}} \tag{3}$$

$$\Delta Pl = 0.412h\frac{(\varepsilon_{reseff}+0.3)\left(\frac{Pw}{h}+0.264\right)}{(\varepsilon_{reseff}-0.258)\left(\frac{Pw}{h}+0.8\right)} \tag{4}$$

Where, h is the height of the substrate, and ε_{reseff} is representing the effective dielectric constant which is estimated with the help of applying (5).

$$\varepsilon_{reseff} = \frac{\varepsilon_{res}+1}{2} + \frac{\varepsilon_{res}-1}{2}\left[1 + 12\frac{h}{Pw}\right]^{-1/2} \tag{5}$$

The aforementioned (5) are utilized for calculating the length and width of the antenna patch. The (6) and (7) are applied for calculating the feed line length and width:

$$Fl = \frac{1}{4}\lambda_g \tag{6}$$

$$Fw = \frac{7.48 \times h}{e^{\left(z_0\frac{\sqrt{\varepsilon_{res}+1.41}}{87}\right)}} - 1.25 \times t \tag{7}$$

where, Fl is representing the length of feed line, Fw is denoting the width of feed line, t is representing the thickness of the path material, and λ_g is denoting the guided wavelength which is computed by (8):

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{rseff}}} \tag{8}$$

where, λ is representing the wavelength of the frequency and it is estimated by applying (9).

$$\lambda = \frac{c}{f_{res}} \tag{9}$$

After calculating the length and width of the feed line, the substrate length and width is computed by utilizing (10) and (11):

$$Sl = 6h + Pl \tag{10}$$

$$Sw = 6h + Pw \tag{11}$$

where, Sl is denoting the length of the substrate and Sw is denoting the width of the substrate. For ground plane dimensions, the values which are obtained from substrate length and width are considered. The values which are obtained from the calculation is optimized to attain an optimal and effective results.

The recommended FRA is shown in Figure 1. the suggested antenna, which consists of two capacitances, two shunt-series switches, one resistance, and one inductance. There is a shunt connection as well as a series connector. When the switch is turned ON, the resistance and capacitance values are dropping and rising, respectively. Similar to this, to turn the switch to the OFF position, you need to increase resistance while lowering capacitance. This assumes that the capacitance, resistance, and inductance are 1 F, 1 O, and 0.4 nH, respectively, for the ON state. However, it is assumed that the capacitance, resistance, and inductance are, respectively, 0.5 pF, 1 Gohm, and 0.4 nH for the OFF state.

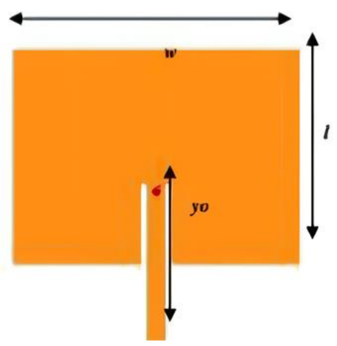

Figure 1. Proposed frequency reconfigurable microstrip patch antenna

3. RESULTS AND DISCUSSION

Fluid may be pumped into a hollow behind the antenna using this kind of reconfiguration technology, changing the substrate's relative electric permittivity or magnetic permeability. Adjustments to

the antennas' characteristics are therefore possible. The study of smart materials for RAs is new. An antenna with reversible polarisation for broadband applications is shown in Figure 2. It is a two-arm, unidirectional radiation antenna that is mounted on a large ground plane. To provide various polarisations, two water tubes are positioned above the ground plane. A left-handed or right-handed circular polarisation of the antenna may be achieved by varying the water flow via the water channels. Within the frequency range of 1.2-1.84 GHz is the antenna's operating band. A unique RA design is presented, using intelligent materials. The frequency of a coaxially fed patch antenna may be changed by using transformer oil that has a high frequency and low loss. Between the ground plane and the radiating patch of the proposed antenna, there is a two-layer substrate. The whole patch radiator substrate's effective permittivity is changed to generate the frequency reconfiguration by varying the height of the oil layer, which affects the volume ratio of liquid to air. The surface of the ground plane is made of aluminium plate.

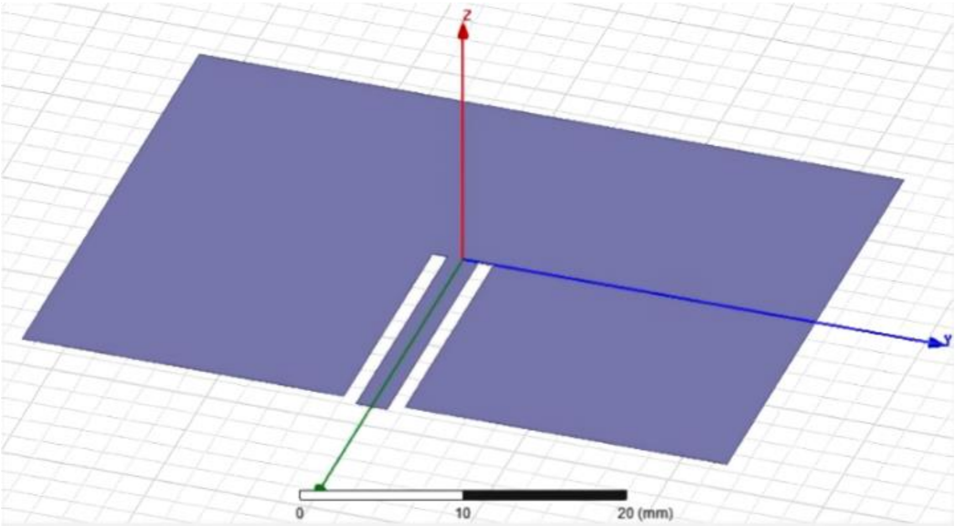

Figure 2. Proposed antenna design

Conventional microstrip antennas are limited to one working frequency, a narrow span of impedance, limited gain, bigger size, and issues with polarisation. There are many ways to improve the performance of traditional microstrip antennas: metamaterial, EBG, photonic band gaps (PBG), frequency selective surfaces (FSS), stacking, and alternative feeding methods. Due to its straightforward structural layout, the microwave component with defected ground structure (DGS) has shown to be more prevalent among all the strategies for parameter optimisation that have been reported. On the ground plane of the microstrip circuit, carved slots or other defects are referred to as "defective ground structure". DGS may be associated with a single ground plane defect or many defects. The first report on DGS for filters smaller than the microstrip line was made. Below the microstrip line, DGS has been utilised to minimise mutual coupling, reduce higher mode harmonics, and create band-stop characteristics. Since DGS has been effectively used in the filter industry, it is presently in high demand for a variety of uses. The development and history of DGS are covered in this article. The fundamental ideas, use guidelines, and corresponding models of the various DGS forms are described. Microstrip antenna radiation properties have been improved by the use of DGS by increasing bandwidth and gain, suppressing higher mode harmonics, and reducing cross-polarization and mutual coupling between neighbouring components. This study provides an overview of DGS's uses in microwave technology and addresses its usage in antennas.

Wideband, small, low-profile, high-performance, and reasonably priced antennas are often able to meet the demanding specifications of contemporary wireless communication systems. Portable, effective gadgets that can function at low signal strengths and quick data speeds are essential to modern communication. Scientists have been working on building and enhancing RF front ends in an attempt to fulfil the most recent necessities. A wide range of unique techniques have been put forward to improve a microwave component's performance. With both diodes off, Figure 3 shows the return loss. The periodic structure of the ground plane acts as a rejection band. However, modelling the PBG structure for millimeter-wave and microwave components is particularly challenging. Several characteristics impact the PBG band gap parameters, such as the quantity of lattices, forms, distances, and percentage of relative volume. When D2 is turned on and D1 is turned off, the return loss is shown in Figure 4. Another parameter is radiation

from etched faults that repeat. The only instrument used in an additional ground plane aperture (GPA) approach is a microstrip line implanted with a central slit at the ground plane. Bandpass and 3 dB edge coupler filters are well-known products from GPA. The width of the GPA has a significant impact on the characteristic impedance of the microstrip line and determines the degree of return loss. The return loss for the ON and OFF stages of both diodes is shown in Figure 5.

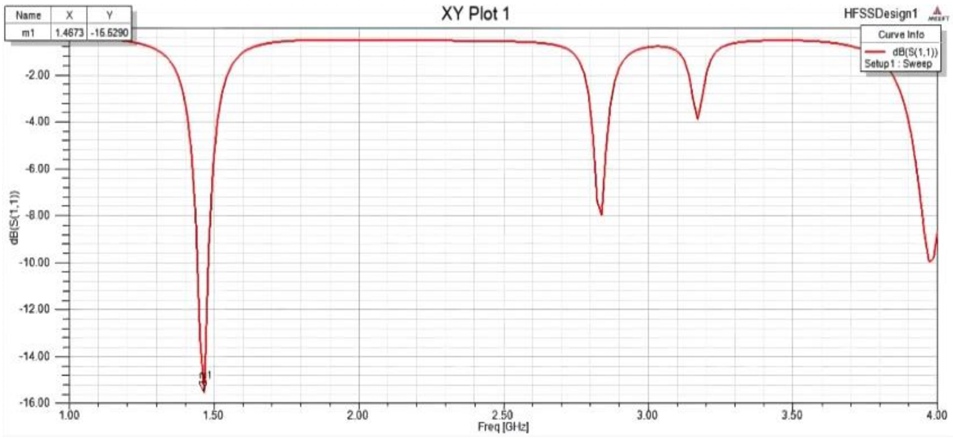

Figure 3. Return loss with both diodes are OFF

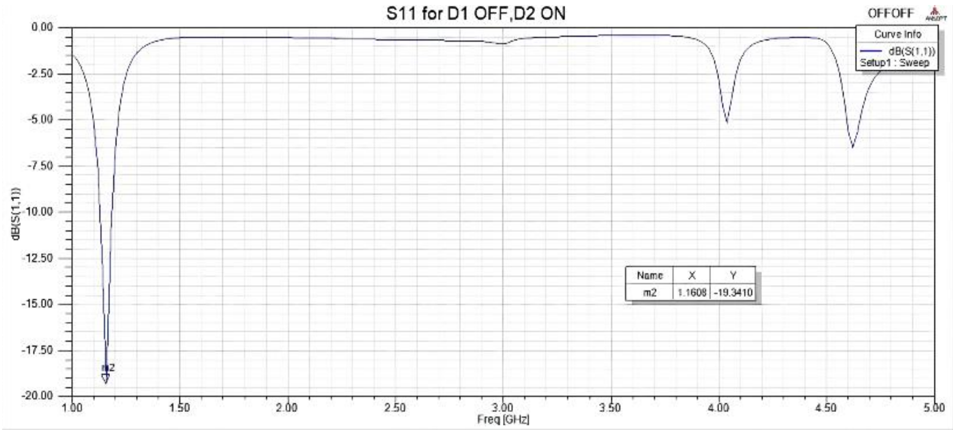

Figure 4. Return loss with D1 OFF and D2 ON

Figure 5. Return loss with D1 ON and D2 OFF

In order to address these issues, originally developed DGS, which was a word used to identify a single fault shaped like a dumbbell. Given that the EBG structure also has a band-stop function; it is conceivable to consider it to be simplified in a manner similar to the DGS. DGS may be used by scientists researching microwaves on a variety of subjects. Several applications in microwave circuits as well as several new DGSs have been put forward and thoroughly investigated. With both diodes on, Figure 6 shows the return loss. There has been much discussion over the evolution of DGS. Three books on DGS-based microstrip antennas have been released since then.

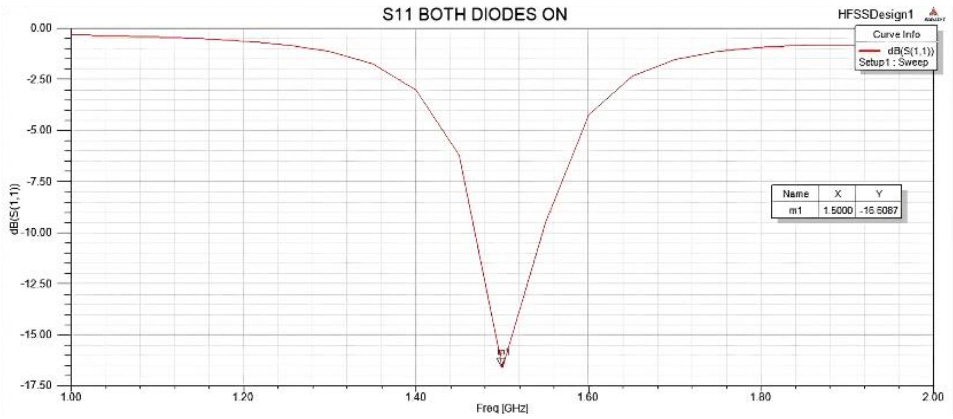

Figure 6. Return loss with both diodes are ON

The need for compact, cost-effective, and interoperable RAs and antenna arrays is being driven by the industry's rapid advancements in wireless communications. In many military and commercial applications, having a single antenna that can be dynamically changed to transmit and/or receive on several frequency bands is important. This has piqued the interest of reconfigurable multiband antennas. Space-based radar, unmanned aerial vehicles, communication satellites, electronic intelligence planes, and many more communications and sensing applications employ these antennas.

Using a single monolithic batch manufacturing method, it is possible to combine the antenna, transmit/receive switch, and RF circuits into a packed module, which is one of the most important advancements towards reducing size and cost. RF-MEMS switches are used on a variety of forms and geometries to produce a range of applications, including the planar inverted F-shape antenna (PIFA), E-shape, S-shape, spiral, and fractal. RAs are multi-scale devices, hence one analytical tool is insufficient to adequately quantify them. However, if many analytical techniques are used to a single structure, it turns into a computationally demanding process requiring the utilisation of significant computer power. These days, NNs may be used as effective modelling tools for a wide range of input-output interactions. Due to their remarkable ability to learn from data, generalise patterns seen in data, and replicate nonlinear correlations, NNs have a broad variety of applications in engineering [6]. The most recent reconfigurable multiband antenna designs largely rely on NNs and evolutionary algorithms.

Metal structures called antennas are used to transmit and receive electromagnetic radiation. An antenna is a structure that serves as a conduit between a guiding system, such a transmission line or waveguide, and open space. That component of a transmitting or receiving system that is intended to emit or receive electromagnetic waves define an antenna. Microstrip antennas are renowned for being rigid, lightweight, low profile, inexpensive, flexible in how they may be installed on both planar and non-planar surfaces. Mobile communications devices are the primary use for them because of their adaptable designs and affordable prices. RECAP and microstrip antenna topologies have attracted interest as ways to provide tunability across many octaves. The development of RF-MEMS switches has led to a recent surge in interest in reconfigurable multiband slot antennas. Another name for microstrip antennas is patch antennas. Typically, the dielectric substrate is photo-etched with the radiating components and feed lines. The radiating patch may be shaped into whatever shape you choose, including triangles, elliptical shapes, squares, rectangles, circles, and thin strips (dipoles). The radiation pattern is shown in Figure 7.

The most popular shapes are square, rectangular, dipole (strip), and circular because of their low cross-polarization radiation and appealing radiation properties. These shapes are also the easiest to produce and analyse. One benefit of these antennas is that their patterns radiate similarly over a wide range of frequencies. The well-researched Sierpinski gasket is the main precursor. Multi-band or micro antenna

designs have been influenced by the many fractal patterns that exhibit self-similarity. Fractal antennas have been made using a variety of fractal geometries, including the Koch island, Hilbert curve, Minskowsi, Sierpinski gasket, and Sierpinski carpet.

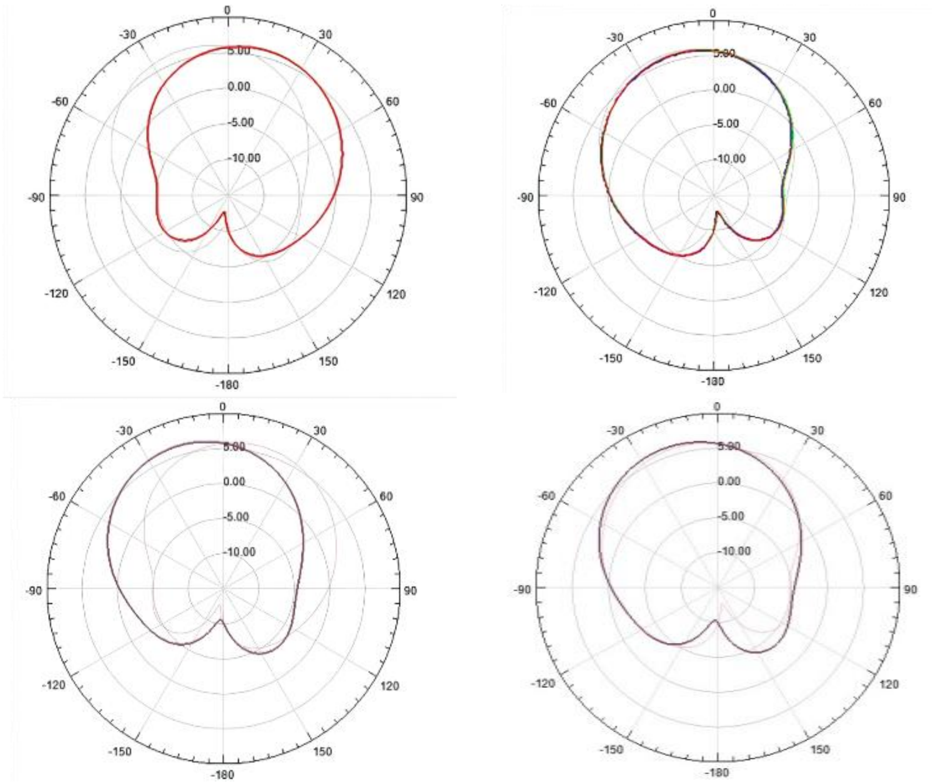

Figure 7. Radiation pattern of the proposed antenna

4. CONCLUSION

The major goal of this project is to build a trustworthy MPA for wireless communication systems by using a shunt-series RF-MEMS switch for frequency adjustment. Here, ON-ON, OFF-ON, ON-OFF, and OFF-OFF switching conditions are used in the design and simulation process utilising the HFSS programme. Designing parameter values is another step that involves the use of the Maxwell equations. First, the shunt-series RF-MEMS switch in HFSS is used to construct the MPA. The simulation technique is then conducted using the three switching situations of ON-ON, OFF-ON, and OFF-OFF. The performance of the suggested antenna design is assessed using antenna performance metrics such as radiation pattern, bandwidth, gain, VSWR, and return loss. The performance matrices provide the basis for obtaining the simulation results for each of the three scenarios. Finally, the findings show how much more effective and appropriate the suggested frequency reconfigurable MPA is for the wireless communication system.

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